Adapting a VRI Irrigation Scheduling System for Different Climates

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Abstract. An irrigation scheduling supervisory control and data acquisition (ISSCADA) system was developed by scientists at USDA-ARS in Bushland, Texas. The system was comprised of hardware and software components for control and decision support for center pivot variable rate irrigation (VRI) management and designed for use in a semi-arid region. Multiple years of field studies have demonstrated that the ISSCADA system produced yields and water use efficiencies similar to or better than irrigation scheduling based on weekly neutron probe readings. However, the system had not been tested in other climates. Beta tests were conducted at USDA-ARS laboratories located in sub-humid and humid climates by outfitting VRI center pivots with the ISSCADA system. The goals of the beta tests were to demonstrate that irrigation management with the ISSCADA system produced crop yields and water use efficiency (WUE) or irrigation water use efficiencies (IWUE) generally comparable to or better than those obtained when scheduling irrigations according to best local management practices. Results demonstrated that crop yields for corn and cotton managed with the ISSCADA system were similar to those produced using local irrigation scheduling methods. Water use efficiencies for corn were also similar among irrigation management methods, while IWUE was greater for cotton produced with the ISSCADA system in a sub-humid climate.

Keywords*: Center pivot, crop water stress index, GIS-database, plant feedback, soil water sensing feedback, wireless sensor network systems*

Introduction

The irrigation scheduling supervisory control and data acquisition (ISSCADA) system has a hybrid architecture of hardware and software components for control and decision support for center pivot variable rate irrigation (VRI) management (Andrade et al., 2015; 2016 and 2017). The system was patented at Bushland, Texas (Evett et al., 2014) and uses plant feedback as the primary algorithm for irrigation scheduling. The plant feedback method is based on the theoretical crop water stress index (CWSI) derived by Jackson et al. (1981). The ISSCADA system uses varying levels of pre-established thresholds of an integrated CWSI (iCWSI) to determine irrigation timing and amount (O'Shaughnessy et al., 2013 and 2015). The iCWSI is the summation of the CWSI at one-minute or five-minute time steps during pre-selected daylight hours. The ISSCADA system can also incorporate feedback from soil water sensing stations to ensure closed-loop control and prevent over- and under-irrigation (Figure 1).

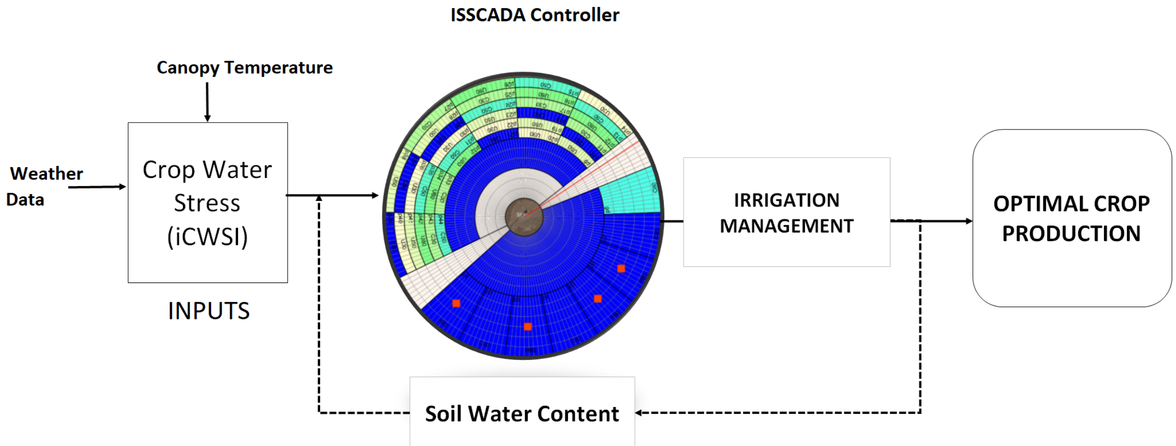


Figure 1. Graphical depiction of the Irrigation Scheduling Supervisory Control and Data Acquisition system showing roles of wireless sensor networks in feedback for optimal crop production.

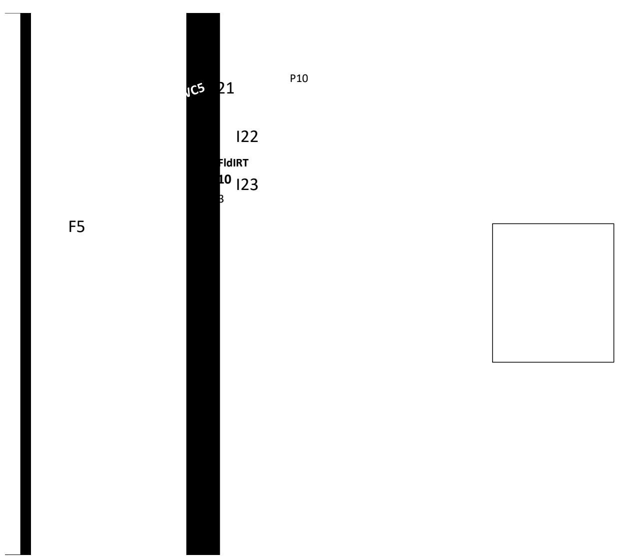
The core hardware components of the ISSCADA system included wireless sensor network systems for monitoring canopy temperature (infrared thermometers- IRTs, Dynamax Inc., Houston, TX), weather, and soil water content (optional). Data from the wireless network systems and the center pivot are collected at an embedded computer at the pivot point for centralized data assembly, information processing, dynamic prescription map building and site-specific sprinkler irrigation control. The ISSCADA software is of a server-client architecture. The server software is GIS-based and was developed by USDA-ARS (Andrade et al., 2017). Because the ISSCADA system was developed in a semi-arid climate, at the Conservation and Production Research Laboratory in Bushland, TX. The initial operation of the system and some of the ancillary hardware were adapted for VRI center pivot sprinkler systems designed to reduce water losses due to evaporation. For example, the sprinkler spacing on these center pivots is typically 5 ft apart and the application method is low elevation spray application (LESA) with nozzles approximately 1.5 ft above the ground or low energy precision application (LEPA) drag socks (Lyle and Bordovsky, 1983), where the double open-ended socks are dragged in the furrows. The radii of throw for LESA and LEPA sprinklers is < 12 ft. enabling light-weight brackets to be mounted on the center pivot truss rods to hold the wireless network of IRTs forward of the irrigation spray, viewing a dry canopy. The LESA and LEPA application methods allow prescription maps to be built from data collected while the ISSCADA system is irrigating as well as when it runs dry. Furthermore, the two wireless IRTs required in each control zone were located at the borders, facing inwards towards the center of the VRI management zone (MZ) at an oblique angle. The number of MZs and sensors in each MZ was determined by the user.

Beta testing of the ISSCADA system began at two USDA-ARS sites in addition to the ARS Conservation and Production Research Laboratory (CPRL) in Bushland in 2016. During this first year, only the plant feedback method was used to schedule irrigations. In 2017, soil water sensing stations were installed and used in the ISSCADA system in Florence and Bushland. Soil water sensors were installed in 2017 in Portageville but not incorporated into the ISSCADA system for irrigation management. At Stoneville, the ISSCADA system was delayed from being fully operational until the diesel-powered system was converted to electrical and the CAMS panel was powered continuously from the grid. All three of the locations were located east of Bushland, Texas in climates that are more humid than a semi-arid climate. One of the major concerns of using the ISSCADA system to schedule irrigations in humid climates is that high moisture content in the air can reduce crop transpiration and increase canopy temperature independently of soil moisture (Wanjura and Upchurch, 1997) resulting in false positive irrigation signals leading to over-irrigation. This paper addresses the adaptations made in the operation and architectural design of the ISSCADA system to accommodate the differences in center pivot sprinkler design, irrigation practices, and climate and crop choice, and reports preliminary results in crop yield and irrigation water use efficiency.

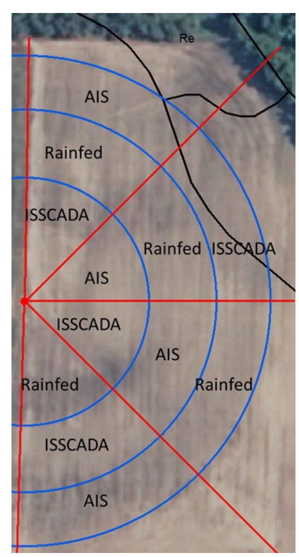
The goals of the beta tests were to demonstrate that irrigation management with the ISSCADA system produced crop yields and water use or irrigation water use efficiencies generally comparable to or better than those obtained when scheduling irrigations according to best local management practices.

Materials and Methods

A mid-maturing corn hybrid (Dekalb DKC64-69 GENVT3P) was managed at the Coastal Plain Soil, Water and Plant Conservation Research Center in Florence, South Carolina (a humid climate). Treatments were irrigation scheduling with soil water potential (SWP) measurements, the ISSCADA system and rainfed treatment plots, each with eight replications (Figure 2a). Cotton, variety PHY 333WRF, was grown at the University of Missouri Fischer Delta Research Center Marsh Farm at Portageville, Missouri (a sub-humid climate) under a 3-tower VRI center pivot using the Arkansas Irrigation Scheduler (AIS) method, the ISSCADA system, and rainfed treatment plots, each with four replications (Figure 2b). At Florence and Portageville, the goal was to maximum crop yields. At Bushland, a mid-season corn hybrid (Pioneer P1151AM) and a short season corn hybrid (P0157AM) were managed under a three- and a six-span VRI center pivot system, respectively. Yields and water use efficiencies from the ISSCADA treatment plots were compared with treatment plots irrigated using weekly neutron probe readings and refilling a percentage of soil water depletion to field capacity. At this location, the ISSCADA system was used to manage both speed-control VRI to maximize yields and zone-control VRI to control irrigation levels.



(a)



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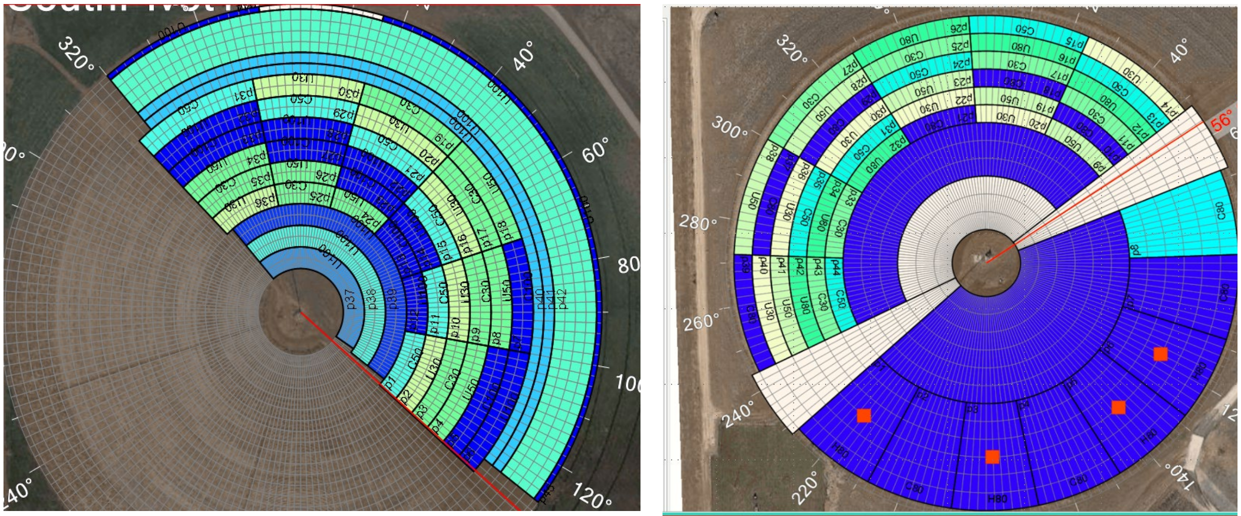

(c) (d)

Figure 2. Plot plans for the beta testing performed on the ISSCADA system at three USDA-ARS laboratories: (a)Florence, South Carolina in 2017, (b) Portageville, Missouri in 2016, (c) six-span at Bushland in 2016, and (d) three-span at Bushland, Texas in 2017.

Each ISSCADA system had a minimum of 2 IRTs located in each control zone, and two IRTs located in a well-watered area of the field. The IRTs on the center pivot pipelines in Florence and Portageville were mounted on steel brackets fabricated by Valmont Industries that extended approximately 15 ft beyond the pipeline and clamped the IRTs at an angle 45° from nadir and a 45° horizontal angle relative to the direction of pivot travel. Standalone weather stations using sensors (to measure air temperature, RH, solar irradiance, and windspeed) and dataloggers from Campbell Scientific (Logan, Utah) were in each field in Florence and Bushland. In Portageville, weather data was automatically downloaded from the University of Missouri website before midnight, using a feature in the ARS client-server program. In all locations, each ISSCADA MZ was managed independently of every other ISSCADA MZ within each beta test field.

In the second year (2017), the Portageville study was modified to include 5 replications. In addition to the IRTs, soil water sensors were installed in Florence, Portageville and under the 3-span center pivot in Bushland. Irrigation scheduling with the ISSCADA system in Florence was based on plant feedback and soil water sensing feedback. In Portageville, the ISSCADA method was based only on plant feedback, while in Bushland, treatment methods by the ISSCADA system included both plant feedback and plant and soil water sensing feedback. When soil water sensing information was used by the ISSCADA system, soil water depletion levels were assessed before the calculated iCWSI values were compared with pre-established thresholds. If soil water depletion was less than the minimum threshold, no irrigation was applied. If the maximum soil water depletion threshold was exceeded, a pre-determined irrigation amount was applied. If soil water depletion was between the minimum and maximum threshold values, irrigation was applied based on the plant feedback thresholds. Three iCWSI thresholds with corresponding irrigation amounts were established for each ISSCADA system. An example of the iCWSI and soil water sensing thresholds are shown in Table 1 for Bushland. Pre-determined thermal stress thresholds were crop specific and pre-determined irrigation amounts were region specific and determined after interviewing the users.

Table 1. Integrated CWSI thresholds for VRI zone control irrigation management and irrigation amounts (inches) (top half) and soil water depletion thresholds for VRI speed control for irrigation management of corn hybrid (P1151AM) grown at Bushland, TX.

	2017			
	Northwest half of field			
Zone	**Treatment Type**	Irrigation Threshold1	Irrigation Threshold2	Irrigation Threshold3
Zone	**Plant feedback**	100<iCWSI<= 150	150<iCWSI <=250	iCWSI > 250
Zone	**C80**	0.60	0.80	1.2
Zone	**C50**	0.38	0.50	0.75
Zone	**C30**	0.23	0.30	0.45
	Southeast half of the field			
	Hybrid Plots- 1,3,5,6			
Speed	**Soil + Plant feedback**	If soil water depletion in 1.5 m < 0.10 (in the root zone)	If 0.10 < soil water depletion < 0.5 (in the root zone)	If soil water depletion in 1.5 m > 0.50 (in the root zone)
Speed	**Irrigation amount**	0.0 inch	Use iCWSI Threshold Levels shown for Plant feedback for C80 Treatment type	1.0 inch
Speed	**Plant Feedback Plots – 2,4,7,8**			
Speed	**C80**	**100<iCWSI<= 150**	**150<iCWSI <=250**	**iCWSI > 250**
		0.60	0.80	1.2

Besides adapting irrigation amounts, it was necessary to adjust the operation of the ISSCADA system outfitted onto the VRI center pivots in Florence, Portageville and Stoneville. Sprinkler spacing for the center pivot in Florence is 5ft, while sprinkler spacing for the center pivots in Portageville and Stoneville were 9 ft. apart. Nozzle height for all three sprinklers was at mid-elevation height (approximately 5 to 9 ft. above the ground). This configuration resulted in radii of throw > 12 ft. The brackets holding the wireless IRTs did not extend their field-of-view beyond a wet canopy. This required the ISSCADA system to be run dry across the cropped area of the field before building a prescription map. In addition to differences in sprinkler design, irrigation and agronomic practices differed in these humid and sub-humid regions as compared to the semi-arid climate of Bushland. Smaller irrigation amounts per irrigation event were common in the sub-humid and humid regions because water losses due to evaporation were minimal under conditions of high relative humidity (RH) and lower average wind speeds. Often, irrigation management practices in sub-humid and humid regions are such that depleted soil water in the profile is filled to less than field capacity to leave storage for unpredictable precipitation events and reduce surface runoff (Nguyen et al. 2015).

The ISSCADA system was customized for each center pivot system by inputting information that was specific to the climate, design and operation of the center pivot sprinkler, crop type, planting date, and local irrigation practices. Information regarding the location of each IRT sensor on the pipeline, its identity, the location of each soil water sensing station, its identity, and the depth of each TDR at the location was used to automatically build prescription maps for management by the ISSCADA method.

The USDA-ARS Crop Production Systems Research Unit in Stoneville, Mississippi managed soybean (HBK4955 Libertylink) under a four-span VRI center pivot outfitted with the ISSCADA system. The system integrated both IRTs and TDRs for plant and soil water sensing feedback. Irrigation scheduling with the ISSCADA system was compared with a VRI irrigation scheduling method that employed a static prescription for MZs labeled VRI (Figure 3), whereby irrigations were triggered when soil water depletion reached a pre-established threshold level. The goal was to maximize crop water use efficiency. Soybean crops were planted under the pivot on April 20, 2018. The total precipitation and ET_o were 644mm and 438mm, respectively, in 2018. Using the ISSCADA system, three dry-scans were performed on June7, June 27, and July 25, respectively. Starting from June 9, seven irrigations were conducted according to the ISSCADA outputs and the soil moisture measurements of a sensor-based irrigation scheduling method. 0.75" water was applied in each irrigation event to the MZs at 100% irrigation rate in VRI treatment. Amount of water applied to the ISSCADA treatment was dynamically determined by the ISSCADA system based on the information from the dry-scan. Crops were harvested on Oct. 4, 2018. As of this date, yield data were not processed. This study will be repeated in 2019.

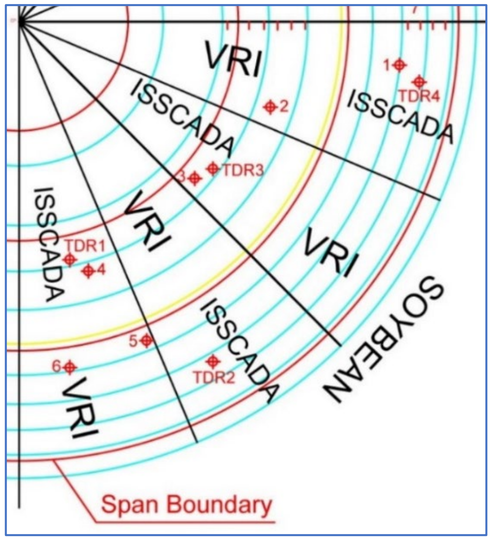

Figure 3. Plot plan and sample prescription map for four-span VRI center pivot located at Stoneville, Mississippi in 2018.

Preliminary Results

Florence, SC

In the first year (2016), the outfitting of the ISSCADA hardware onto the VRI center pivots in Florence and Portageville did not occur until mid-June. Therefore, the system (using only plant feedback) was tested during the reproductive stage of corn in Florence. Approximately of 20 in. of precipitation was received from April through August. Irrigations were terminated after July 8, when the crop was in the dent stage and due to abundant precipitation. Grain yield (15.5% MC), water use efficiency (WUE) [(grain yield/(precipitation + irrigation+ water stored in the soil)] and irrigation water use efficiencies (IWUE) [(irrigated grain yield- rainfed yield)/irrigation] for the SWP (153.9 bu ac^{-1}, 7.04 bu ac^{-1} in^{-1}, 73.9 bu ac^{-1} in^{-1}) and ISSCADA (149.3 bu ac^{-1}, 7.01 bu ac^{-1} in^{-1}, 94.3 bu ac^{-1} in^{-1}) plots were similar and both were significantly greater than the responses from the rainfed treatment.

In 2017, precipitation totaled 17.9 inches, with most of the rainfall occurring in June and July. The beta test in Florence was repeated, with a change in the management of the ISSCADA treatment plots, such that the ISSCADA system used both plant- and soil water sensing feedback for irrigation scheduling in all eight replications. There was a total of seven irrigation events. Mean corn plot yields and WUE for the three irrigation treatments were similar with 172.4, 162.8 and 169.0 bu ac^{-1}; and 2.54, 3.35 and 3.70 bu ac^{-1} in^{-1} for the SWP, ISSCADA and rainfed treatments, respectively. Irrigation water use efficiency was significantly greater for the SWP treatment.

Portageville, MO

In 2016, Portageville received 17.9 inches of precipitation from May through September, while reference evapotranspiration (ET_0) (ASCE, 2005) was 20.9 in. The average maximum and minimum air temperatures for the growing season were 87.7 °F and 68.8 °F, respectively. Two irrigations were applied to the AIS treatment plots totaling 1.5 inches. One of the ISSCADA treatment plots received two irrigations totaling 1.12 inches, and one irrigation totaling 0.87 inches was applied to the other three ISSCADA treatment plots. Regression analysis for seed cotton yield for AIS, ISSCADA and rainfed treatment plots were 2625, 2849 and 2404 lbs seed cotton ac^{-1}; mean irrigation water use efficiency (IWUE) was 197.32 lbs ac^{-1} in^{-1} and 447.24 lbs ac^{-1} in^{-1} for the AIS and ISSCADA plots, respectively.

Portageville received 16.34 in. of precipitation in 2017 during the months of May through September. The average maximum and minimum air temperatures were 86.3 °F and 67.0 °F, respectively. All of the AIS plots received six irrigations for a total of 4.4 inches. Two of the ISSCADA plots received a total of 3.0 inches of irrigation (5 events), while two received 2.5 inches (3 events) and one received 1.9 inches of irrigation (3 events). Seed cotton yield for the AIS, ISSCADA and rainfed plots were 2634, 2704 and 2219 lbs ac^{-1}, respectively. Mean IWUE was significantly greater for the ISSCADA treatment.

Bushland, TX

The 2016 growing season was hot and dry until August. Total precipitation from May through September was 11.26 in. with more than 61% occurring in August, while ET_o was 32.0 in. Under the 3-span VRI center pivot, a total of 19 irrigation events occurred on plots irrigated manually using information from weekly neutron probe readings and from the treatment plots irrigated with the ISSCADA system using both VRI speed and zone control. Under VRI speed and zone control, grain yield and WUE for the P1151AM corn hybrid was 267 bu ac^{-1} and 10.1 bu ac^{-1} in^{-1}; and 274 bu ac^{-1} and 9.9 bu ac^{-1} in^{-1}, respectively.

In 2016, under the 6-span VRI center pivot system, grain yield and WUE for corn hybrid, P0157AM, managed by manual irrigations at the 100%, 50% and 30% treatments were 198, 176 and 150 bu ac^{-1}, and 7.8, 8.3 and 7.5 bu ac^{-1} in^{-1}, respectively. Treatment plots managed by the ISSCADA plant feedback system resulted in grain yield and WUE of 212, 191, and 176 bu ac^{-1}, and 8.3, 8.0, and 8.4 bu ac^{-1} in^{-1}, respectively.

The beta test for VRI speed and zone control were repeated in 2017 under the 3-span VRI center pivot. A mild spring was experienced with 7 inches of precipitation occurring January through mid- May. However, after planting, minimal rainfall occurred for the next 22 days and a total of four 1-inch irrigations were applied uniformly across all plots, approximately every fifth day. A hailstorm hit on July 2 and damaged leaves and corn stalks on every plant. The damage from the storm slowed crop maturity by approximately two weeks and resulted in an estimated 20% yield penalty. Total rainfall from planting to harvest was 18.5 in. Four of the eight plots managed using VRI speed control used plant and soil water sensing feedback for irrigation scheduling, while plots managed with VRI zone control used only plant feedback for irrigation scheduling. There was no significant difference between grain yield and WUE for plots managed with plant feedback only (202.4 bu ac^{-1} and 7.19 bu ac^{-1} in^{-1}) and plots managed with the combination of plant and soil water sensing feedback (204.3 bu ac^{-1} and 7.35 bu ac^{-1} in^{-1}). Grain yields for the VRI zone control plots using the weekly neutron probe readings were 205, 198, and 135 bu ac^{-1}, and 7.50, 7.68, and 5.29 bu ac^{-1} in^{-1}; compared with 207, 202, and 169 bu ac^{-1} and 7.13, 7.42 and 6.75 bu ac^{-1} in^{-1} for the plots managed by the ISSCADA system at the 100%, 50% and 30% iCWSI thresholds, respectively.

Summary and Future Work

Beta tests performed on the ISSCADA system in the humid and sub-humid regions of Florence, SC and Portageville, MO demonstrated that the ISSCADA developed in Bushland required some modifications to the way the system was operated to develop dynamic prescription maps and that irrigations per each event were typically less than practiced in Bushland. Furthermore, the iCWSI values were adjusted in the software when daytime RH was high. In Florence, the ISSCADA performed as well as irrigation management using SWP measurements, however, the ISSCADA system was not used for the entire growing season during 2016 and in both years, irrigation was limited due to plentiful rainfall. In Portageville, MO, seed cotton yields produced with the ISSCADA method were similar to the AIS method in both years, while IWUE for the ISSCADA system was significantly greater compared with the AIS scheduling method. Results reported from Bushland, showed that corn managed with the ISSCADA system under VRI speed and zone control produced grain yields and WUE similar to irrigation scheduling using weekly neutron probe readings in 2016 and 2017. Beta tests in this semi-arid location also demonstrated that the ISSCADA system can control irrigation treatment levels using a combination of iCWSI thresholds and corresponding irrigation amounts.

Future work will include changing the software interface to make the ISSCADA system easier to operate. Also, more beta test sites representing different climates will utilize the ISSCADA system for irrigation management of soybean and grain crops. It is also anticipated that scientists at the Alberta Agriculture and Forestry Research Centre in Lethbridge, Canada will compare the ISSCADA system with irrigation management practices common for farmers in this region using a grain crop.

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